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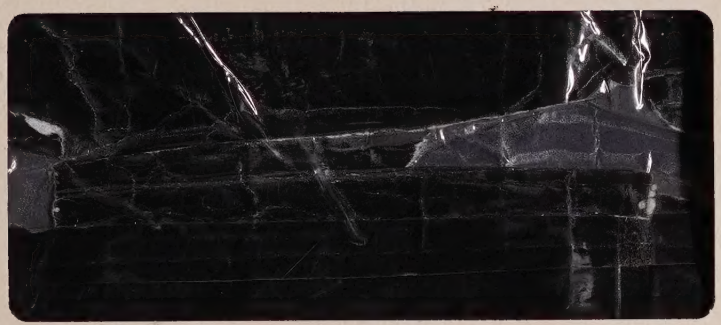
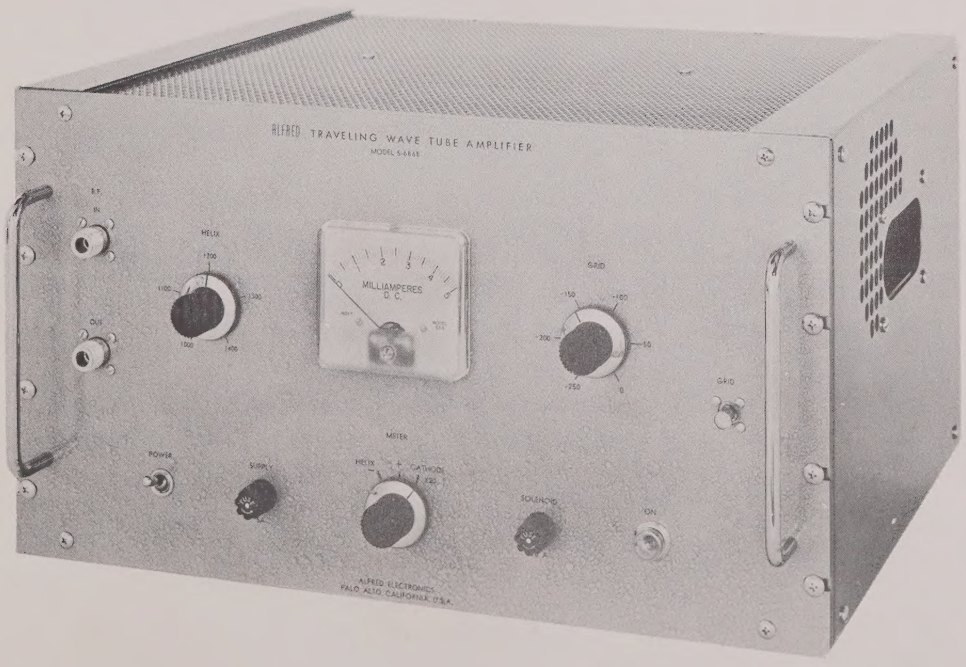


ALFRED ELECTRONICS 3176 PORTER DRIVE, PALO ALTO, CALIF.

MICROWAVE AMPLIFIER
MODEL 5-6868

Serial No. 113



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ADDENDUM SHEET

Model 5-6868

Date	Change No.	Effective S/N	Description
-19-63	12152	118 & up	Paragraph 2-4: Last sentence of fourth paragraph delete, "to give panel HELIX control calibration within 2%." Paragraph 3-2: To line 8, add this note. "This voltage can be monitored at TP-1 and TP-2". Paragraph 4-2: Line 5 Replace "...indications are within 2% for any setting." with "... range covered is within the limits of 980 to 1428 volts."

MICROWAVE AMPLIFIER
MODEL 5-6868

SPECIFICATIONS

Frequency Range:	2.0 to 4.0 Gc
Saturated Power Output:	10 watts minimum, into 50 ohm load
Gain (small signal):	33 db minimum
(at max. power output):	20 db minimum
Gain Adjustment:	0 to 30 db minimum gain and power level reduction by adjustment of panel GRID control from 0 to -250 volts.
Noise Figure:	40 db maximum
Spurious Modulation:	At least 35 db below output signal level.
RF Impedance:	50 ohms
RF Connectors:	Type N female
VSWR (Input and Output):	3:1 maximum
External Modulation (Grid)	
Connection:	Panel BNC receptacle capacitively coupled to TW tube grid. External signal adds to internal DC bias. Diode clamps signal positive peak to cathode potential.
Control Characteristic:	Gain and power output decrease proportionally to negative grid voltage at about .11 db/volt.
Response:	10 cps to above 10 mc/s
Input Impedance:	500 K, shunted by approximately 55 mmfd.
Metering:	Helix or cathode current on 3" front panel meter, selected by front panel switch. Helix voltage available at rear for checking with external precision voltmeter.
Front Panel Controls:	GRID voltage (0 to -250 volts) HELIX voltage (1100 to 1400 volts) METER current switch
Power Supply:	All electrode voltages are regulated except TW tube heater and solenoid. Protective relay shuts off TW tube electrode voltages upon helix overcurrent.
Input Voltage:	105 to 125 volts, 60 cps, approximately 960 VA.
Physical:	Bench mounting with perforated metal dust covers. Sides with recessed handles may be removed to permit rack installation. Height: $10\frac{1}{2}$" Width: 19" Depth: 15" from panel, $16\frac{1}{2}$" overall
Finish:	Panel, gray hammertone Sides, top and bottom, dark metallic gray
Weight:	80 pounds

SECTION 1 - GENERAL

1-1 DESCRIPTION

The ALFRED Model 5-6868 Microwave Amplifier is a stable, wide band, high gain power amplifier and modulator of microwave signals in the frequency range of 2 to 4 Gc. It consists of a traveling wave tube, its focusing solenoid, and a power supply arranged in a compact and versatile unit. Thus the varied and unique traveling wave tube characteristics may be conveniently applied to laboratory and systems use. Some possible applications are:

1. Power amplification of wide band signal generator outputs or complex modulated RF signals, including RF pulses with rise times as short as a few millimicroseconds.

2. RF modulation by application of pulses or other AC signals to TW tube grid.

3. Isolation of a load from a microwave signal source.

4. Generation of extremely stable microwave oscillations either at fixed frequency or tunable over a wide range, using an external resonant feedback network.

On the front panel of the Model 5-6868, type N fittings are provided for RF input and output. A BNC receptacle permits AC coupled connection to the TW tube grid. Controls for grid and helix voltages are provided to optimize performance for specific applications. A panel meter may be selected by a switch to monitor either TW tube Helix or Cathode current.

The TW tube requires no RF adjustment, is encapsulated for protection, and is easily replaced.

The Model 5-6868 is built as a convenient laboratory bench instrument. However, simply by removal of outside sheet metal sides, it may be mounted in a standard relay rack.

SECTION 2 - THEORY OF OPERATION

2-1 GENERAL DESCRIPTION OF TW TUBE

The physical arrangement of the traveling wave tube is indicated in Figure No. 1. The electron gun produces a beam of electrons which travel down the axis of the helical wire coil to the collector. The magnetic flux from the surrounding solenoid restricts the beam to travel axially along the tube just inside the helix. RF signals at low impedance are coupled to the helix at the electron gun end, and travel down the metallic path of the helix. The velocity of the electron beam is critically adjusted by the potential difference of the cathode and helix so that the beam velocity down

the axis is just a little faster than the progressive RF signal of the helix. The field of the helix RF signal causes the electrons to bunch, so that at the collector end, their increased field returns to the helix an amplified signal which is coupled out through a low impedance connection. Reflections down the helix are prevented by the attenuator, consisting of lossy material positioned between RF input and output. The low impedance connections to the helix and the relatively long effective path for interaction with the beam make possible uniform amplification over a broad band of frequencies. To simplify the tube and its power supply, the last anode in the electron gun is internally connected to the helix.

Amplitude modulation is accomplished in the gun by varying the beam density in accordance with a voltage applied to a control grid. A more complete description and associated pertinent information are presented in the Engineering Notes at the end of this Manual.

2-2 TW TUBE PERFORMANCE CHARACTERISTICS

Gain and Power Output vs. Frequency

Figure No. 2 shows typical curves of small signal gain, gain at maximum output, and maximum power output as a function of frequency. These curves are taken with helix voltage fixed at rated broadband value. The small signal gain is better than 30 db over the frequency range of 2 to 4 Gc. Gain at maximum output is greater than 20 db over the same frequency band.

Power Output vs. Power Input

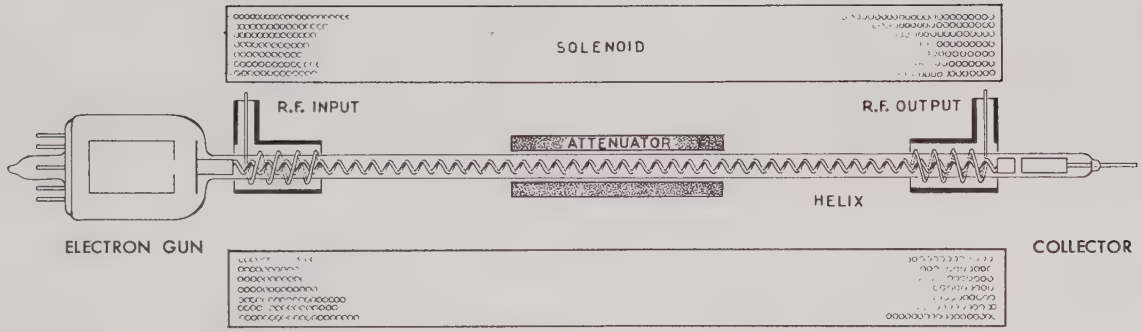
Figure No. 3 shows power output vs. power input performance at 3 frequencies. The curves exhibit the typical traveling wave tube characteristic in that power output is a linear function of power input, until the output level is about 6 db below maximum value. Beyond this the curve becomes non-linear, levels off, and then decreases as greater RF input is applied.

Grid Characteristics

Figure No. 4 shows curves of relative power output and gain vs. grid voltage at mid-band for several values of grid voltage. The grid is a low current electrode operated negatively with respect to TW tube cathode. It controls beam current, gain and power output of the TW tube. Varying grid voltage with an external signal applied to the panel GRID connector can achieve fast response amplitude modulation of beam and RF output.

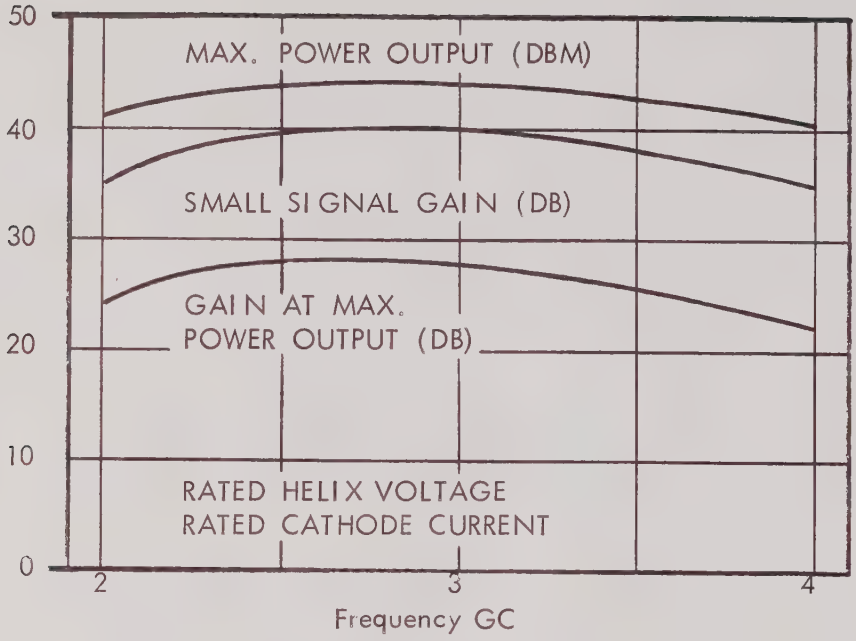
2-3 RF LOAD

The TW tube may be operated at any cathode current up to rated value, into a RF load with a maximum VSWR of 3:1. Performance will be stable without spurious oscillations, but output power will be less into mismatched loads.

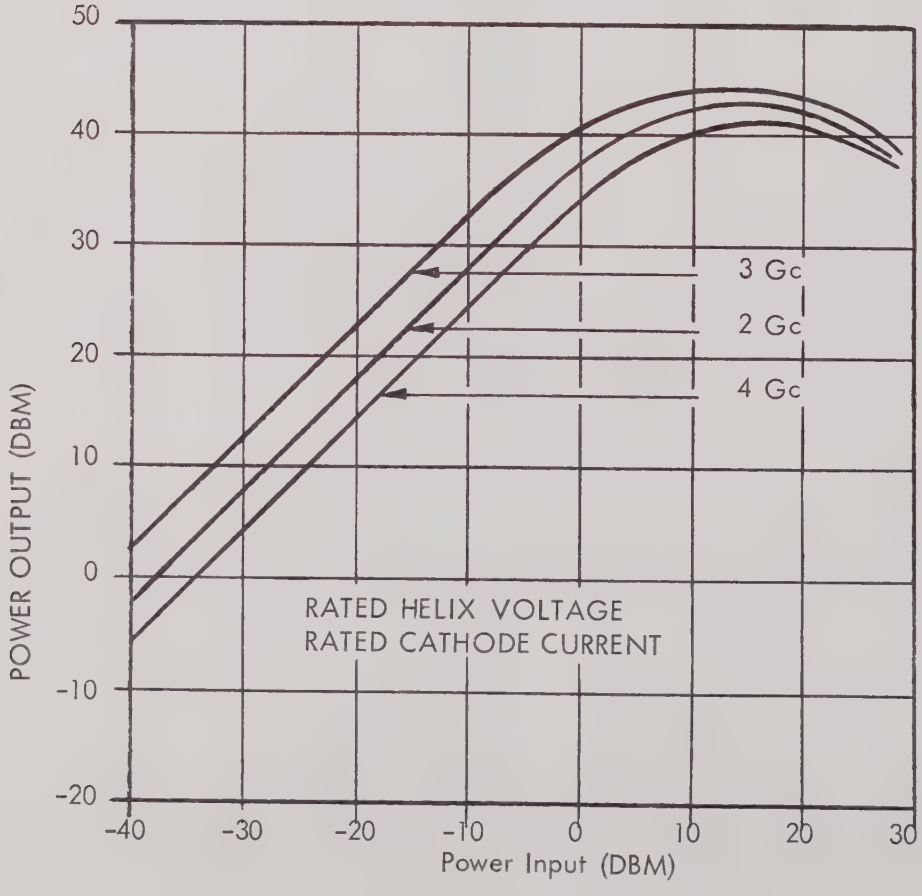


Schematic View of Traveling-Wave Tube

FIGURE 1



POWER OUTPUT AND GAIN VS. FREQUENCY
Figure 2



POWER OUTPUT VS. POWER INPUT
Figure 3

GRID CHARACTERISTICS

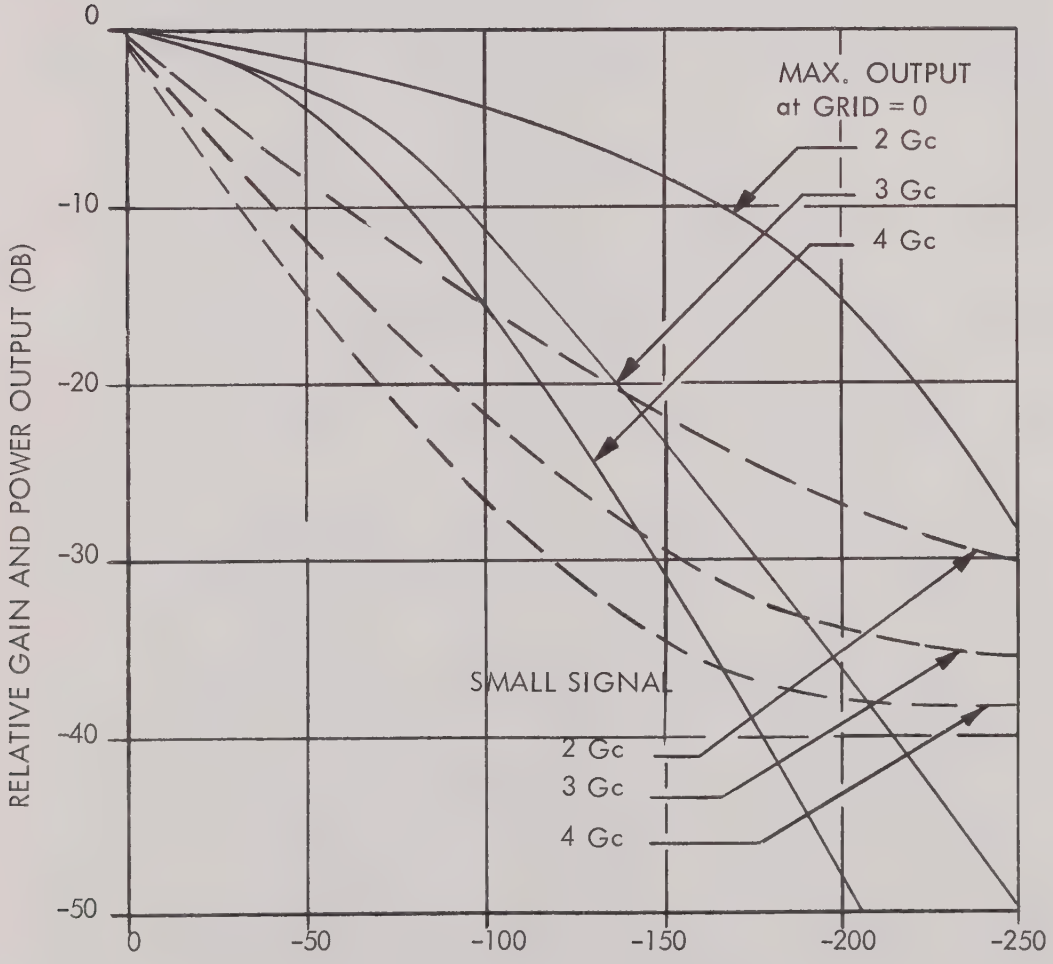


Figure 4

2-4 CIRCUIT DESCRIPTION

In this manual, reference to a panel control is by capital letters and underlined - chassis controls by capital letters only.

Referring to the schematic diagram, input power is applied to selenium rectifier SR3 through POWER switch SW2, SOLENOID fuse F1, and contacts of relay RY3. Direct current from SR3 is filtered by L1, C18, C19, C20 and fed to focusing solenoid L2. A normally closed thermal switch mounted in L2, opens if its temperature exceeds 200° F. RY3 is thereby released and DC power to solenoid is removed. Excessive temperature may damage both TW tube and solenoid and could result from blower failure or abnormal ambient temperature.

Power for transformers T1, T2, T3, T4 and blower B1 passes through POWER switch SW2 and SUPPLY fuse F2. The voltage doubling arrangement of V1, V2 and C2, C3, C4 and C5 produces approximately 1800 volts. This is fed through series regulating tubes V3, V4, V5 connected in parallel and controlled by amplifier tubes V6 and V7 to obtain electronically regulated helix-anode and collector voltage. Reference voltage developed across V9, V10 is compared with supply output voltage at the grids of differential amplifier V7. The amplified difference at the plates of V7 is applied to the cathode and grid of the left half of V6 by using the right half of V6 as a cathode follower. The difference voltage further amplified is then applied to the grids of the series regulator tubes.

Helix voltage is sampled by a resistor divider network consisting of precision resistors R21, R22, R23 and potentiometers R24 and R25. The voltage is changed by varying the ratio of the divider network with panel HELIX control R25. The HELIX CALIB. potentiometer R24 permits adjustment of the resistance ratio to compensate for slight differences in reference tube operating voltages. R24 is factory set, using a 1/2% accuracy meter, connected to the rear HELIX VOLTAGE terminals TP1 and TP2, to give panel HELIX control calibration within 2%.

TW tube helix and anode current is passed through relay RY2 which operates when the current exceeds 5 ma. RY2 contact closure actuates RY1, which in turn removes all high voltage from the TW tube. This protection is required, should the electron beam strike the helix for any reason, such as misalignment or loss of solenoid current. The large beam current would overheat the fine wire of which the helix is formed, severely damaging it and driving out gas which would deteriorate cathode emission. Interlock relay RY1 is de-energized by momentarily turning off POWER switch SW2.

The cathodes of series tubes V3, V4 and V5 furnish high current directly to the TW tube collector. Regulator tube V8 provides an essentially constant drop of 105 volts between the TW tube collector and helix.

TW tube grid bias voltage is obtained from voltage doubling rectifier SR2 supplied by transformer T3, filtered by C6, and C7, and regulated with V11 and V12. Regulated 250 volts is connected across GRID potentiometer R27. Adjustable bias voltage for the TW tube grid is obtained from the arm of R27. V13 prevents positive excur-

sions of the grid and clamps the positive peak of any external modulating signal to TW tube cathode potential.

Transformer T1, rectifier SR1 and filter C1 provides +140 volts for the screen grids of V3, V4 and V5. Indicator lamp I1 is connected across this supply and thus is energized by closure of power switch SW2. RY1 is also operated from this supply.

Meter switch SW1 selects either TW tube helix-anode or cathode current to pass through M1. Two helix-anode current positions are provided, one for normal meter polarity and one for reversed. Secondary emission from the TW tube collector often gives reversed helix-anode current. For simplicity, panel labeling for SW1 indicates HELIX + and HELIX - whereas actually anode current is also included in the meter reading.

SECTION 3 - INSTALLATION AND OPERATION

3-1 INSTALLATION

Upon receipt, carefully unpack and inspect the instrument for damage received from transit. Should any damage be found, follow procedure outlined on "Shipment Damage Claim" page at the end of this Manual.

The instrument is designed for either bench or rack operation in normal ambient temperatures. Air flow through the unit and from the solenoid exhaust should be completely unrestricted. Operation in the presence of very strong magnetic fields should be avoided unless external magnetic shielding is provided. Primary power requirements are 105 to 125 volts, 60 cps, approximately 960 voltamperes. If operation at other voltage or frequency is contemplated, consult manufacturer.

The Model 5-6868 is supplied with gray sheet metal sides containing handles. If the instrument is to be rack mounted, the four screws at the corners of each handle side and the screws at each edge of the panel, should be taken out and the sides removed. Insert size 8-32 screws to hold the sheet metal side covers in place. Unit is now ready for inserting into rack. Supports should be provided in the rack to carry the weight of the Model 5-6868 upon its insertion or removal. CAUTION - ambient air near instrument must not exceed 135° F.

3-2 SETTING-UP PROCEDURE

The procedure outlined in this sub-section refers specifically to first-time operation of the unit. However, following a storage period or after repair, the setting-up procedure should be repeated. Should the TW tube be replaced, the new operating information is on the data page supplied with each new tube. Proceed as follows:

1. Before turning on power, disconnect or turn off any grid modulating voltages and set panel controls:

   GRID at -250
   HELIX to voltage value shown on test sheet in rear of manual
   Meter switch to HELIX +

2. Turn on power and allow amplifier to warm up at least 5 minutes.

3. Slowly turn up GRID towards 0, noting that helix-anode current should not exceed 5 ma. Should meter indication be reversed, change meter switch to HELIX - position. Secondary emission from the collector usually gives negative helix-anode current indication. TW tube behavior will determine which meter polarity is required. If current exceeds 5 ma with below GRID setting of 0, the TW tube probably requires mechanical realignment in its solenoid.

   Alignment is accomplished by removing top and bottom perforated dust covers and adjusting the TW tube positioning screws at each end of the solenoid. To permit adjustment, first loosen the lower vertical locking screw at each end of the solenoid. These screws may be reached from the bottom of the instrument. Using adjusting screws which go in at an angle to the steel end ring, orient TW tube to obtain the lowest helix-anode current, all the while advancing GRID control towards 0. ADJUST CAREFULLY TO AVOID HIGH HELIX CURRENT DURING ADJUSTMENT. Should helix-anode current accidentally exceed 5 ma, overcurrent relay will shut off power supply. Operation can be restored by turning POWER switch off and then ON.

   Positioning of the TW tube is most easily accomplished with two screwdrivers, one in each hand. Starting with the tube approximately in the center of the solenoid, slowly wobble the tube with the alignment screws to minimize helix-anode current. Should helix current reverse, change panel meter switch to HELIX position of opposite polarity. Position the adjusting rings on each end of the solenoid using the two front or two rear screws. Once a null is reached, change rear screws or both front screws slightly and then relocate the null with the other pair of screws. Often the new null is lower than the original. If not, move the rings in opposite direction relocating the current null each time. With a little care, helix-anode current usually can be reduced to safe value. Helix-anode current up to about 5 ma is quite safe. However, the lower the current the less chance that gas will be driven from the helix due to high temperature operation. Gas would soon damage the cathode emission and render the TW tube inoperative. Lower current also reduces modulation of the RF output by beam noise and stray magnetic fields. When best null is obtained, tighten locking screws to hold TW tube and rings firmly.

4. When GRID can be set to 0 with helix-anode current at or below 5 ma, change meter switch to CATHODE X20. Current should be equal to operating value of cathode current given on the test data sheet enclosed at the rear of this manual.

5. Apply RF. Input power up to 1 watt will not cause damage. However, only a level less than 50 milliwatts should be used. If RF output can be observed, adjust, if necessary, helix voltage slightly for optimum per-

formance. See also sub-section following titled, SYNCHRONISM. Note setting of HELIX control so it can be returned to correct position if accidentally moved.

6. If possible, pulse or square wave modulated RF input should be applied, and the amplifier output detected and observed on an oscilloscope. If significant 120 cps modulation is noted, very slight repositioning of the TW tube in the solenoid may be required to null out stray magnetic fields from the power transformers in the instrument. Both helix-anode current and AC field nulls occur at essentially the same mechanical positions, so slight turning of the adjusting screws, or rotation of the TW tube a few degrees usually will give best modulation minimum without appreciably affecting helix-anode current. Be sure that locking screws are tightened at the best position and then replace dust covers.

7. Meter switch should be left in CATHODE X20 position during normal operation. An occasional check of helix-anode current is recommended.

8. Turn on or connect to panel GRID connector any grid modulating voltages. Set GRID bias control for best performance. Meter readings will drop in proportion to modulation duty cycle.

SECTION 4 - MAINTENANCE

4-1 GENERAL

CAUTION: Extremely dangerous high voltages exist in this instrument. Observe the utmost care when checking or making repairs.

Routine maintenance need consist of the following:

1. Check blower operation every six months or after 1000 hours use, and oil bearings with a few drops of light machine oil in the oil tubes provided. Regular attention to the blower is essential since its failure could result in damage to the TW tube from overheating.

2. Test at regular intervals, the power supply tubes to detect marginal performance. Any voltage regulator tubes removed for test should be returned to their original sockets. INTERCHANGING OR REPLACING VOLTAGE REGULATOR TUBES WILL NECESSITATE RECALIBRATION OF HELIX SUPPLY VOLTAGE

4-2 CALIBRATION OF HELIX SUPPLY VOLTAGE

Calibration of helix supply voltage is accomplished by connecting a voltmeter having 1/2% accuracy or better to the HELIX VOLTAGE test points on the rear of the unit. Unlock the HELIX CALIB. control, located near the right end of the solenoid. Move panel HELIX control over entire range and note readings. Adjust HELIX CALIB.

control so that voltage indications are within 2% for any setting. Lock HELIX CALIB. control.

4-3 TROUBLE SHOOTING

Should a failure occur, follow a logical procedure to locate the cause. Refer, if necessary, to the Theory of Operation section and the schematic diagram included in this manual. Solenoid fuse F1, if blown, should be replaced with 8 amp, 250 volt, type 3AG. Supply fuse F2, should be replaced with 5 amp, 250 volt, type 3AG. Power supply tubes can be observed, to determine if heaters are operating and voltage regulator tubes lit, by removing screws holding top dust cover and sliding it rearward. Operating voltages for the traveling wave tube may be measured as described below. Correct voltages are indicated on the schematic diagram.

Helix-Anode:	Connect a high resistance DC voltmeter to the test points provided on the rear plate of the instrument.
Collector:	Connect the positive lead of a high resistance DC voltmeter to terminal 19 and the negative lead to terminal 18 of TS1, the terminal strip just rear of panel.
Grid:	Connect the negative lead of a high resistance DC voltmeter to terminal 10 of TS1, the positive lead to terminal 11.
Heater:	Connect AC voltmeter to terminals 7 and 8 of TS1.

If tubes have been tested and found to be normal, and supply voltages are incorrect, it is recommended that power be disconnected and faulty components located by a systematic resistance check.

All panel components are accessible by removing the panel screws near the handles. Power supply components are accessible by removing rear plate.

4-4 BLOWER REPLACEMENT

Should blower fail or wear out, remove left gray handle side and cover by loosening screws near panel and captive screws at each corner. Take off plate at rear of instrument and disconnect motor leads. Remove the three screws holding blower assembly to solenoid deck and lift out blower. To change motor or wheel, remove two screws on air intake ring, loosen wheel set screw, and slide wheel off shaft. Behind wheel, nuts holding motor are accessible. After servicing the blower, follow the above procedure in reverse to reassemble the instrument.

4-5 TRAVELING WAVE TUBE REPLACEMENT

To replace the traveling wave tube, take off gray handle sides by removing screws

near corners at edge of panel and below handle, and remove the left sheet metal cover. Disconnect RF and power cables to the tube. Loosen TW tube adjusting screws. Slide tube out hole in left side.

Follow reverse procedure in installing the new tube. Allen head screws in the solenoid adjusting rings may require slight adjustment to expand the rings slightly for a firm but sliding fit around TW tube. Observe due caution to prevent damaging the tube. Follow SETTING-UP PROCEDURE in OPERATION section, except that new value of helix voltage supplied on the replacement tube Data Sheet should be substituted.

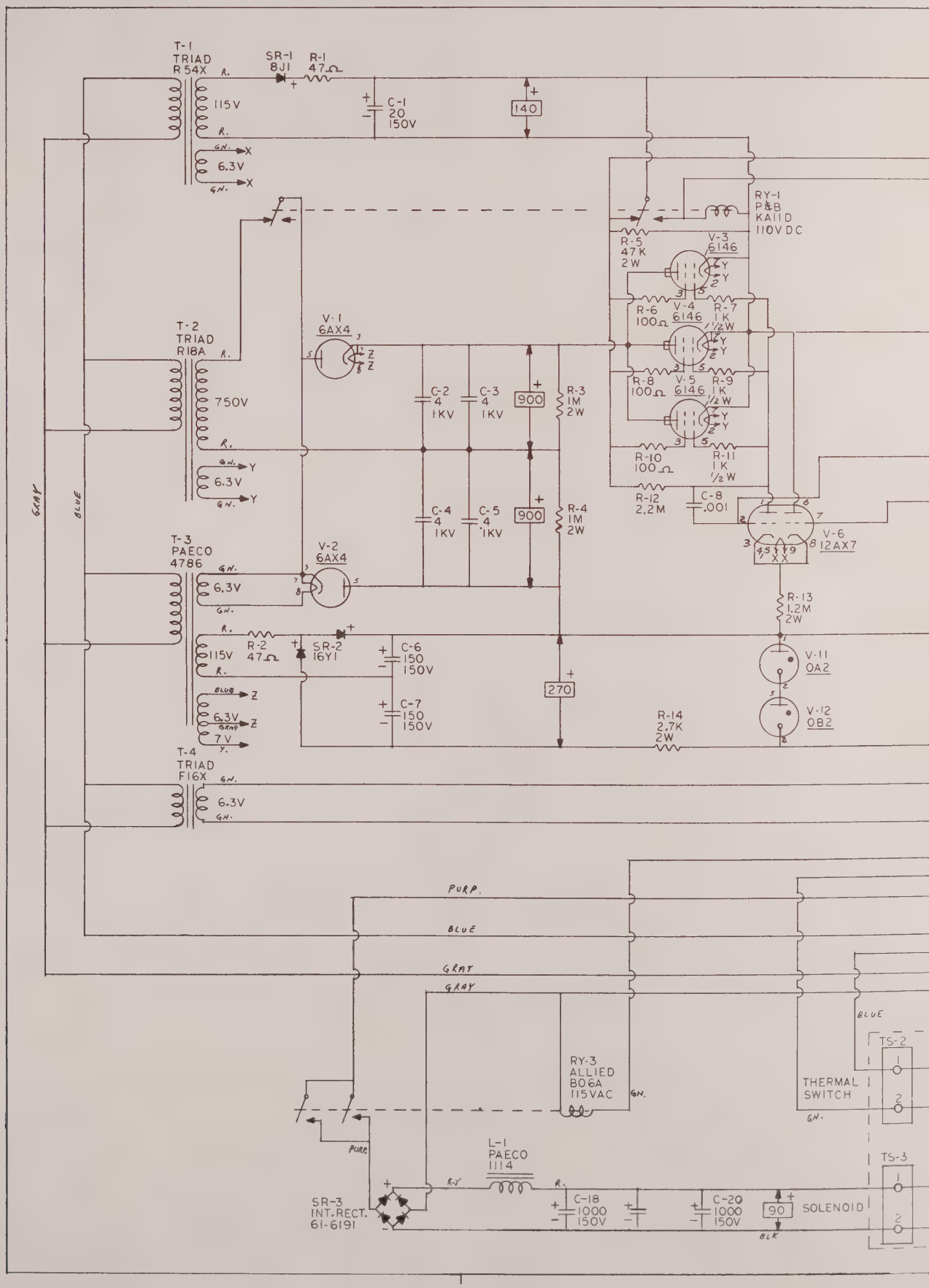
To permit rotation of the TW tube for best alignment, RF leads from the panel may be temporarily disconnected and direct connection made through the hole in the cover side. Avoid excessive air leakage during adjustment. When alignment is complete, install RF leads and replace sheet metal parts. Final orientation of the tube should be such that RF connectors are within $\pm 10^{\circ}$ of horizontal. This is required for maximum air flow across collector radiator fins.

4-6 TRAVELING WAVE TUBE WARRANTY

See Tube Warranty and Replacement Procedure sheet at rear of manual.

4-7 WARRANTY

ALFRED products are warranted against defects in workmanship and materials. This warranty is limited to repair or replacement of products or parts (except tubes, transistors, and batteries) which prove defective within one year after delivery to the original purchaser. ALFRED ELECTRONICS is not liable for consequential damage.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R-1
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C-1
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150V
140
RY-1
P&B
KA11D
110V DC
R-5
47K
2W
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6146
R-6
100Ω
V-4
6146
R-7
1K
1/2W
R-8
100Ω
V-5
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R-9
1K
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R-10
100Ω
R-11
1K
1/2W
R-12
2.2M
C-8
.001
V-6
12AX7
T-2
TRIAD
R18A
750V
6.3V
V-1
6AX4
C-2
4
1KV
C-3
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900
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2W
C-4
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C-5
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1KV
900
R-4
1M
2W
T-3
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R-2
47Ω
SR-2
16Y1
V-2
6AX4
C-6
150
150V
C-7
150
150V
270
R-13
1.2M
2W
V-11
0A2
V-12
0B2
R-14
2.7K
2W
T-4
TRIAD
F16X
6.3V
GRAY
BLUE
PURP.
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GRAY
GRAY
RY-3
ALLIED
806A
115VAC
THERMAL
SWITCH
TS-2
TS-3
L-1
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1114
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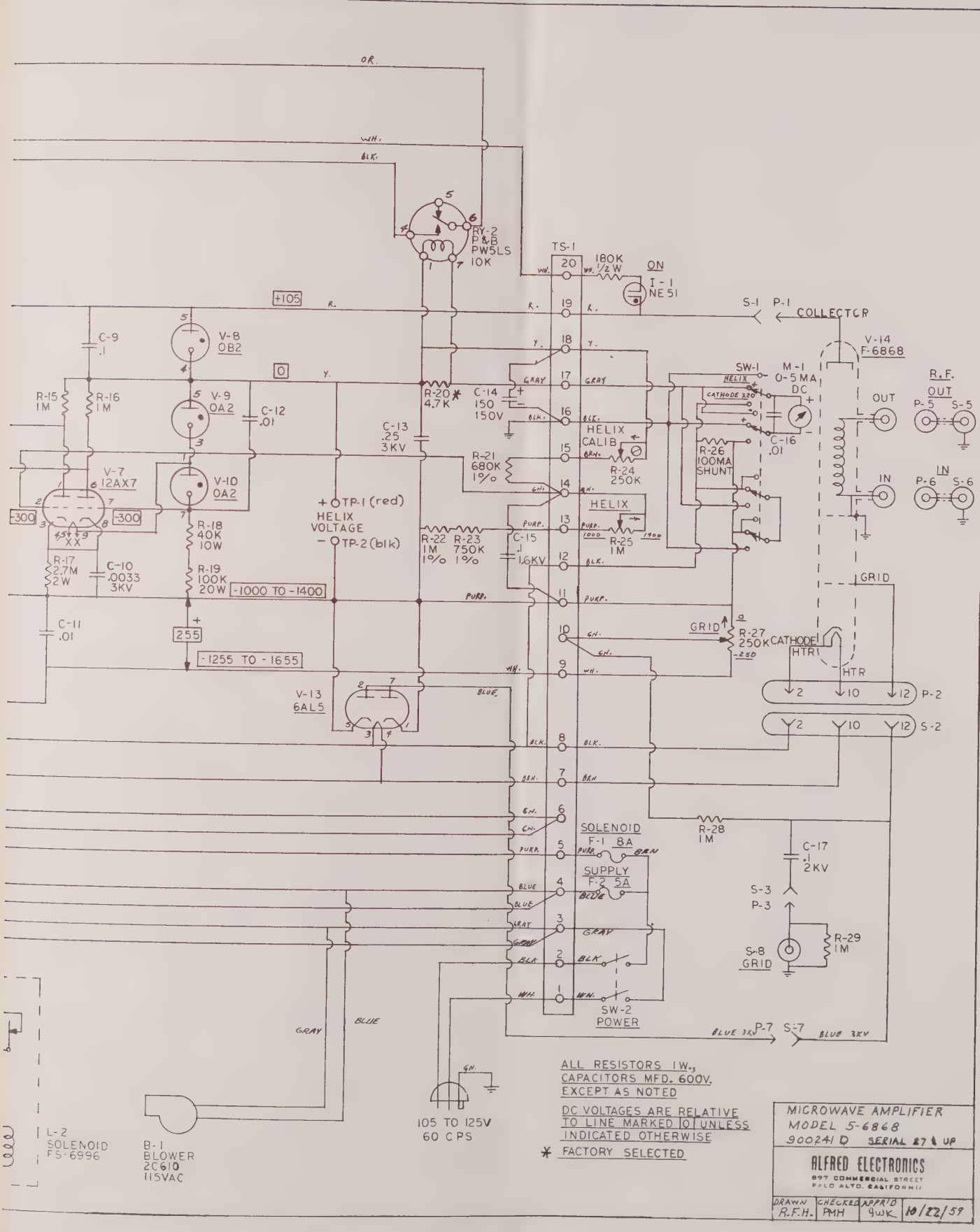
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I-1
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+105
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F-6868
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1M
R-16
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C-12
.01
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4.7K
C-14
150
150V
C-13
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3KV
SW-1
HELIX
CATHODE X20
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V-10
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-300
-300
6.3V
XX
HELIX
CALIB
R-24
250K
R-26
100MA
SHUNT
R-21
680K
1%
+ TP-1 (red)
HELIX
VOLTAGE
- TP-2 (blk)
HELIX
R-22
1M
1%
R-23
750K
1%
C-15
.1
1.6KV
R-25
1M
1000
1900
R-17
2.7M
2W
C-10
.0033
3KV
R-18
40K
10W
R-19
100K
20W
-1000 TO -1400
PURP.
GRID
C-11
.01
255
-1255 TO -1655
GRID
R-27
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-250
CATHODE
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F-1 8A
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GRID
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P-7
S-7
BLUE 3KV
GRAY
BLUE
L-2
SOLENOID
FS-6996
B-1
BLOWER
2C610
115VAC
105 TO 125V
60 CPS
ALL RESISTORS 1W.,
CAPACITORS MFD. 600V.
EXCEPT AS NOTED
DC VOLTAGES ARE RELATIVE
TO LINE MARKED 0 UNLESS
INDICATED OTHERWISE
* FACTORY SELECTED
MICROWAVE AMPLIFIER
MODEL 5-6868
900241 D
SERIAL 87 & UP
ALFRED ELECTRONICS
897 COMMERCIAL STREET
PALO ALTO, CALIFORNIA
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CHECKED PMH
APPR'D GWK
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HUGGINS LABORATORIES
ENGINEERING NOTES
VOL. I, NO. 1 JANUARY, 1955
Published by Huggins Laboratories Sunnyvale, California

GENERAL INFORMATION ON TRAVELING-WAVE TUBES

R. A. Huggins*

Engineers who design circuits which use conventional low frequency vacuum tubes usually have at least a speaking acquaintance with their theory of operation. In designing circuits, or in deciding which type of tube to use, careful use is made of the various characteristic curves associated with these tubes. The following discussion will similarly acquaint the applications engineer with the simple theory of the operation of the traveling-wave tube and familarize him with the various characteristic curves which describe its operation.

MICROWAVE AMPLIFICATION

As the microwave region of the radio frequency spectrum came into practical engineering use, devices were needed which could function as better amplifiers and oscillators. Above a few hundred megacycles conventional vacuum tubes no longer amplify properly because the period of one cycle of the radio frequency wave approaches the time it takes the electrons to travel from cathode to anode. As a result the amplification factor of the tube decreases with increasing frequency until no useful gain can be obtained. This is known as the transit time effect.

The first device which served as a practical amplifier above a few hundred megacycles actually made use of the transit time effect. This device, known as a klystron, became useful primarily as an oscillator. The klystron, however, is also capable of acting as an amplifier. Klystron amplifiers are capable of giving high values of amplification, but they have two serious limitations for many applications: They are relatively narrow band devices which usually have no more than a few megacycles bandwidth between half-power points, and tuning the amplifier to different frequencies requires a mechanical adjustment. The klystron is, however, the forerunner of a general class of microwave electron devices which utilize transit time effects in electron beams. This general class of devices includes the traveling-wave tube (TWT).

A klystron is a narrow band device because it involves the use of a very sharply resonant, high-impedance tuned circuit. It is necessary for a klystron to use such a circuit because interaction takes place with the electrons over very short physical distances, and it must develop high electric fields to have efficient interaction with the electrons. It was reasoned, however, that one might obtain a very broadband amplifying device by using a low-impedance, broadband circuit which developed relatively small electric fields that interacted with the electrons over a long physical distance. Such is the basis on which the traveling-wave tube works, and this basic concept led to a wide range of devices which are useful as broadband amplifiers and oscillators in the microwave region.

The traveling-wave tube yields high values

* President, Huggins Laboratories, Inc.

of amplification over wide frequency ranges with no mechanical tuning mechanism or variation of any voltages or currents applied to the tube. Power amplification greater than 10,000 (i.e., 40 db gain) over a 2:1 frequency range has been obtained with this type of tube. The actual number of megacycles covered by such tubes can be a staggering figure. For example, an operating bandwidth of 2000 megacycles has been obtained in one typical tube type; 7000 megacycles has been obtained in another.

Tubes can be designed to emphasize various special characteristics. For instance, tubes are built which have low noise properties, high power output, or controlled variations of gain with frequency. Many special tubes are designed and built for particular applications.

FORWARD-WAVE HELIX TYPE AMPLIFIER

Among the simplest circuit elements which satisfy the broadband low-impedance circuit requirement of the traveling-wave tube is a simple helical transmission line. On this so-called helix, the radio frequency energy essentially travels at the velocity of light along the wire from which the helix is wound. Since the wire and the energy follow this helical path, progress of the energy along the axis of the helix is at some fraction of the velocity of light. This velocity is determined by the geometry of the helix (i.e., circumference and pitch) and by the dielectric loading due to the structure which supports the helix. The fields associated with this "slow-wave" extend outward and inward into the region adjacent to the helix, and it is into this region that electrons are sent to interact with the waves.

If electrons are directed along the axis of the helix at essentially the same velocity as the waves, an interaction between the waves and electrons occurs wherein the electrons become bunched. As the electrons progress along the axis they become packed into tighter and tighter bunches. Simultaneously, the radio frequency fields on the helix increase in magnitude as they progress down its length. The increase in energy of this "growing wave" is just balanced by a decrease in the average kinetic energy of the electrons in the beam. In other words, the electrons, on the average, have been slowed down and have given up just enough energy to account for the increasing energy or power level in the waves on the helix.

In practice, the electron beam is formed by an electron gun and focused down the center of the helix to a collector electrode at the farther end (see Figure 1). The electron beam is maintained in a tight pencil beam throughout the length of the tube by the confining forces of a longitudinal magnetic field which surrounds the tube. Electron velocity is determined by the voltage difference between the cathode in the electron gun and the helix, and this voltage difference is ad-

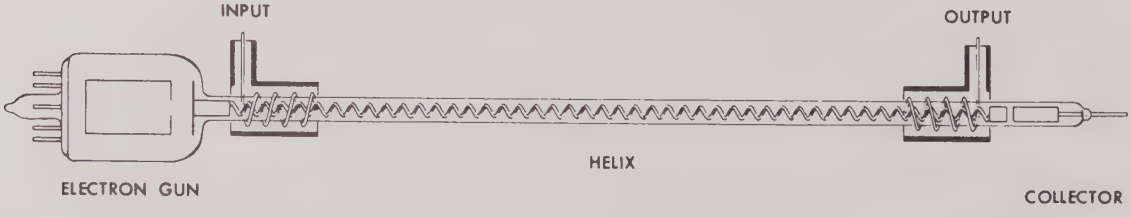

Figure 1. Schematic View of a Traveling-Wave Tube.

justed to give the electrons the right velocity for interaction with the waves. The signal to be amplified is coupled onto the end of the helix nearest the electron gun and propagates along the helix in the same direction as the electron beam. Because of the interaction, the fields on the helix grow exponentially with distance, and these amplified waves are coupled off the helix at the end farthest from the electron gun.

The devices which couple the energy onto and off the helix are special directional couplers which are in themselves helices. These helices are outside the vacuum envelope and are matched to the input and output coaxial transmission lines. This type of coupler is capable of transferring most of the energy from the lines to the main helix, which is inside the vacuum envelope, without making physical contact with the helix. These "coupled helix matches" have the additional advantage of having very wideband transfer characteristic. Further, they are capable of presenting a standing-wave ratio to the coaxial transmission line of 1.5:1 or less.

SPECIFIC CHARACTERISTICS

In the following sections, various characteristic curves that are encountered in traveling-wave tube operation are discussed.

Helix Voltage vs Frequency. A helix is usually designed so that the "slow-waves" travel at a velocity in the range of 1/10 to 1/30 of the velocity of light. If the wave velocity is examined as a function of frequency, it is found that a helix has a general characteristic curve similar to that shown in Figure 2.

In region A, wave velocity varies as a function of frequency; in region B, wave velocity is essentially independent of frequency. A broadband amplifier is normally operated in region B – the "non-dispersive region."

As mentioned before, the electrons must travel at essentially the same velocity as the waves (synchronous velocity) in order to obtain the growing wave interaction. Since the velocity of the wave varies as a function of frequency, the velocity of the electrons must also be varied so that interaction is maintained. Inasmuch as the velocity of the electrons is determined by the voltage difference between the cathode and the helix, there is also a characteristic curve of synchronous helix voltage as a function of frequency (see Figure 2).

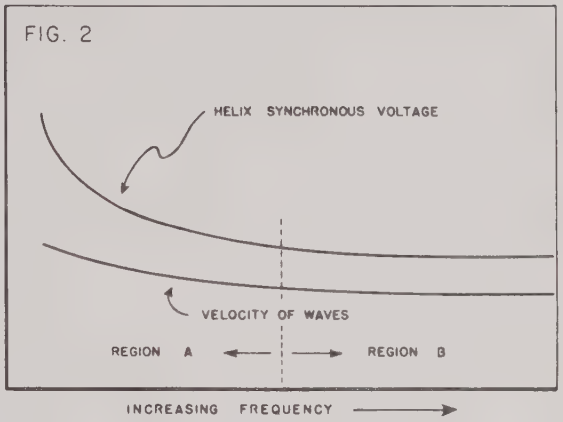

Figure 2. Phase Velocity of the Waves and Synchronous Helix Voltage as a Function of Frequency.

The reason a helix type traveling-wave tube can amplify over wide bandwidths without changing helix voltage can now be easily seen. In the non-dispersive region the synchronous voltage is essentially independent of frequency. That is, the helix voltage which gives the desired interaction between the waves and electrons can be fixed at one value, and this will be the correct value to provide interaction and amplification over a wide range of frequencies.

Gain vs Helix Voltage. To obtain the greatest interaction between the waves and the electrons, and thus the greatest amplification, the helix must be operated at synchronous voltage.

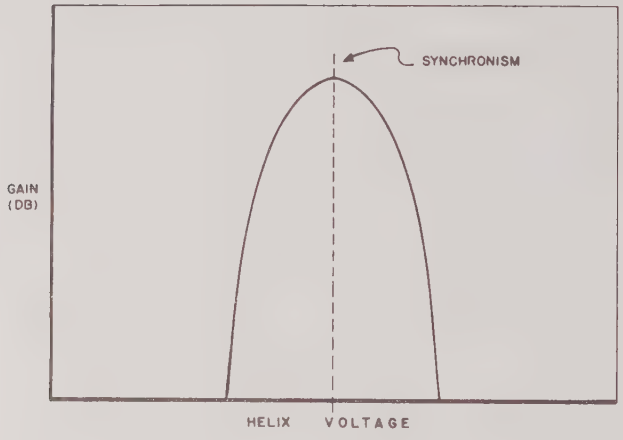

Figure 3. Gain as a Function of Helix Voltage.

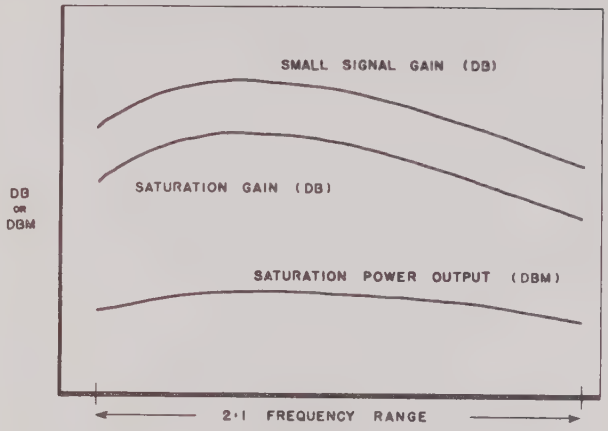

Figure 4. Gain and Power Output as a Function of Frequency.

Should the helix voltage be varied away from synchronism, the gain will decrease as shown by the curve in Figure 3. This characteristic of the TWT is parabolic in shape.

Gain and Power Output vs Frequency. Figure 4 shows a typical plot of gain vs frequency for a fixed value of helix voltage. Small-signal gain is obtained for all values of input signal level except those which drive the tube near its maximum or saturation power output. Saturation gain is the gain obtained when the tube is driven to its saturation power output level. It is seen that the gain and power output curves generally reach a maximum near the center of the band and droop off toward the band edges.

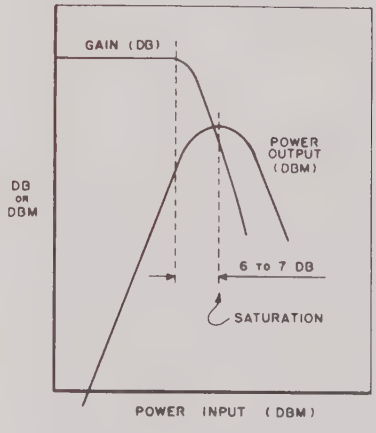

Figure 5. Gain and Power Output vs Power Input at a Fixed Frequency.

Power Output and Gain vs Power Input. Figure 5 shows the variation of power output and gain as a function of power input at a fixed frequency. The amplifier is linear until the power input is within 6 to 7 db of the value which drives the amplifier to saturation. At this point the power output curve begins to droop over, and gain of the tube begins to decrease. At saturation the power output is a maximum, and gain has decreased to the saturation gain level. As the tube is driven beyond saturation the power output drops off, and gain continues to decrease. To obtain maximum power output from an ordinary traveling-wave tube, the right amount of power input must be applied. As will be noted, the saturation region does not exhibit the leveling off or flat saturation characteristic that is found in conventional low frequency amplifier tubes.

Gain vs Beam Current and Grid Voltage. Figure 6 shows that the gain at any fixed frequency is essentially a function of the 1/3 power

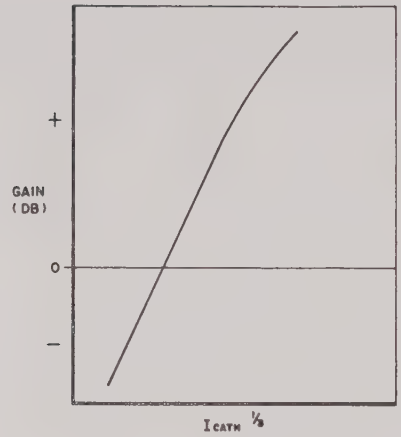

Figure 6. Gain vs Beam Current.

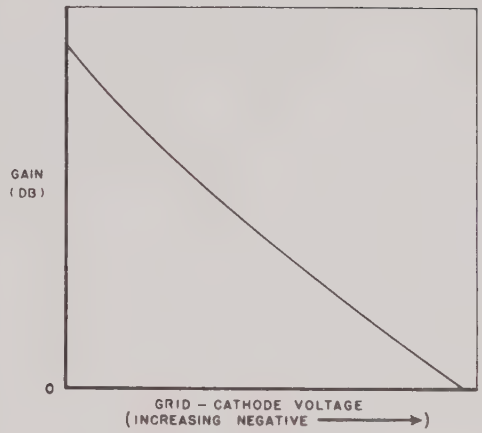

Figure 7. Gain vs Grid Voltage.

of the beam current, and as beam current decreases, gain decreases. Figure 7 shows that the gain of the tube decreases as the grid electrode is made negative with respect to the cathode. This results from the fact that operating the grid negative with respect to the cathode causes the beam current to decrease.

Should the beam current be decreased below a certain value as shown in Figure 6, the gain of the tube measured in db becomes negative, (i.e., the tube is acting as an attenuator). If the beam current is reduced to zero, the net "cold" attenuation of the tube is available. The total change in signal output level as beam current is decreased from its normal value to zero is equal to the sum of the net gain of the tube plus the cold attenuation. This can approach a variation in signal level of about 100 db. Such a change in signal output level is accomplished merely by varying the control grid voltage.

SPECIAL CHARACTERISTICS

Low Noise Amplifiers. A typical low power amplifier may exhibit a noise figure of 20 db. Certain applications require lower noise figures than this. Techniques are available in electron gun design whereby the "shot noise" in the beam can be "de-amplified" before it reaches the beginning of the helix. Special purpose tubes built in this fashion have reached noise figures as low as 6 db.

Narrow Band Amplifiers. Where an application does not require extremely wide bandwidths, tubes can be designed to operate in the dispersive region of the tube characteristic where the velocity of the waves varies as a function of frequency (see Figure 2). In this region, operation at a fixed voltage leads to amplification over only a relatively narrow band of frequencies. Extremely high values of gain (e.g., 60 to 70 db) can be obtained because the problem of controlling spurious oscillations is much simplified since the tube exhibits gain over only a relatively narrow band.

Special Gain Variation. Sometimes special requirements are imposed on the gain variation of the tube as a function of frequency. Tubes can be designed which exhibit an essentially constant value of gain across the band. Others have been built which have linearly increasing gain with frequency. Various other combinations are also possible.

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MICROWAVE MEASUREMENT TECHNIQUES

L. A. Roberts *

As traveling-wave tubes come into more common use, the need becomes apparent for clarification of the various measurement techniques involved in evaluating tube characteristics. In such measurements emphasis must be placed upon broad-band, untuned measuring techniques and test equipment since the traveling-wave tube is a very broadband device. Otherwise, much time would be lost in the repetitive and laborious adjustment and tuning of narrow band devices to make point-by-point measurements across wide frequency ranges.

In this Engineering Note we will concern ourselves with the measurement of small-signal gain, power output, standing-wave ratio, insertion loss, and noise figure. Though automatic and more modern techniques may be available, the methods discussed herein will prove both useful and reliable. Further, these methods require commonly available and relatively inexpensive test equipment.

The types of broadband test equipment commonly used are:

1. Self-tracking tunable signal generator with calibrated power output.
2. Untuned coaxial crystal detector.
3. Untuned coaxial bolometer or thermistor mount with self-balancing power bridge.
4. Broadband coaxial fixed attentuator.
5. Coaxial switch (SPDT).
6. Coaxial slotted section (for VSWR measurements) with untuned detector.
7. Coaxial or waveguide directional coupler.
8. Flourescent noise source.

The emphasis on measuring equipment is placed upon coaxial systems. This is because coaxial test equipment has inherently wideband properties. Waveguide equipment is utilized only when equivalent coaxial equipment is not available or will not do an equivalent job.

SMALL-SIGNAL GAIN MEASUREMENT

A rapid and satisfactory method of measuring gain is to make an insertion gain measurement using the substitution method. This method requires no knowledge of the detector characteristics, nor is absolute power calibration of the signal generator necessary. Accuracy of the measurement depends only on the calibration accuracy of the signal generator output attenuator.

Figure 1 shows a block diagram of the small-signal gain measurement system. With the coaxial switches in position 1, the output of the sig-

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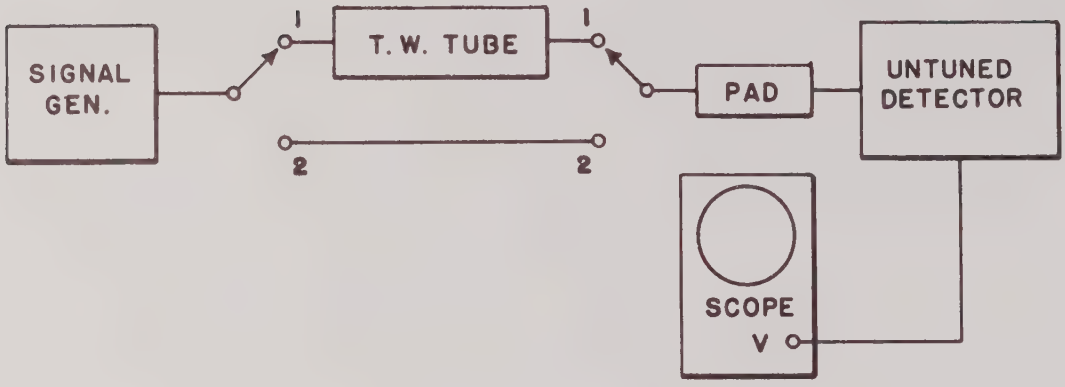

Figure 1. Block Diagram of Gain Measurement System.

nal generator (which has a matched 50 ohm output) is fed to the TWT input through a coaxial single-pole double-throw switch. The output of the TWT is in turn fed through another coaxial switch and a 6 db minimum coaxial fixed attenuator to the untuned detector (If the detector is matched to the coaxial switch, the pad can be eliminated). The detector output is then applied to the vertical deflection channel of an oscilloscope. When the switches are placed in position 2, the tube is by-passed.

Procedure. Apply pulse or square wave modulation to the signal generator. With the tube operating and the switches in position 1, the output attenuator of the signal generator is adjusted to give some convenient deflection on the scope. This is attenuator reading 1. The switches are then placed in position 2 and the attenuator readjusted to give the same deflection on the scope. This is attenuator reading 2. The insertion gain of the tube is then the difference between attenuator readings 1 and 2 measured in db.

Precautions. Both the signal generator and the detector must present good impedance matches as seen by the switch. If they are not matched, reflection losses can give up to several db error in gain. This is the reason for the pad ahead of the unmatched detector, for a 6 db pad guarantees a VSWR of at most 1.5:1.

Also, the switches used must have a low VSWR and very low crosstalk. Crosstalk is stray feedthrough from the input to output terminals of the DPST switch combination through the unused channel. The crosstalk ratio is measured with the TWT removed and is equal to the difference between the signal generator attenuator readings when it is adjusted for equal scope deflection with the switches in position 1 and 2. Regenerative feedback around the switches, which introduces errors in the gain measurement, will be prevented if the crosstalk ratio is at least 20 db greater than the gain of the tube being measured. If the crosstalk ratio exceeds 45 db, it probably cannot be measured with the system in Figure 1. The crosstalk ratio can be measured in such cases with the insertion loss measurement system soon to be described.

Further, care must be taken to insure that the output power level of the tube is at least 10 db below the saturation power level. This eliminates errors due to the decreasing gain characteristic of the traveling-wave tube in the region near saturation.

POWER OUTPUT MEASUREMENT

When making power measurements over wide frequency ranges, it is convenient to use broad-

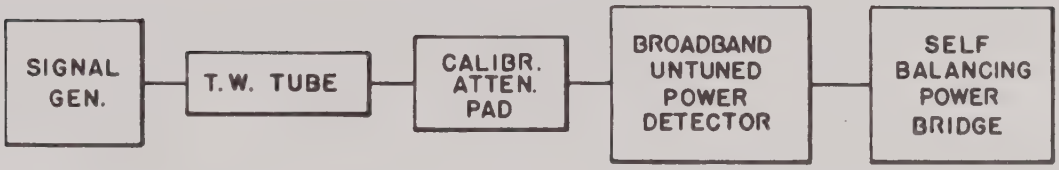

Figure 2. Block Diagram of Power Measuring System.

band (untuned) bolometer or thermistor mounts as power detectors. When these mounts are operated in conjunction with a self-balancing wattmeter bridge, they provide a convenient system for the measurement of absolute power.

If the power level to be measured is greater than the maximum allowable power input to the mount, a calibrated attenuator pad should be inserted ahead of the mount. The most convenient type of pad to use is the resistive film type which has attenuation characteristics that are essentially independent of frequency. Care must be taken not to exceed the maximum input rating of the attenuator.

If power levels to be measured are greater than the rated dissipation of standard attenuator pads, a directional coupler must be placed on the output of the tube. The main arm of the coupler is terminated with a broadband load, and the power detector, with appropriate pads, is placed in the auxiliary arm of the coupler. Broadband coaxial directional couplers with coupling ratios of 10 and 20 db from main arm to auxiliary arm are available.

Should gain measurements be made in conjunction with the power measurements, the power output of the signal generator must be calibrated using its power monitor at each frequency. For accuracy, the power output reading of the signal generator should be initially checked using the bolometer mount and the wattmeter bridge at least over the range of power levels that the bridge can accurately read. Small-signal gain measurements obtained with this equipment should check with the small-signal gain measurements made by the substitution method if the calibration of the attenuator pad and the signal generator is checked.

If all power measurements are recorded in terms of dbm (i.e., db with respect to one milliwatt), the readings of the power bridge, the attenuator (in db) and the signal generator need be merely added and subtracted to obtain power output and gain. Conveniently, most signal generators and power bridges are calibrated in dbm as well as milliwatts.

Figure 2 shows the block diagram of the power measurement system. The power output is given by the equation:

$$\text{Pout (dbm)} = \text{Pad Attenuation (db)} + \text{Ratio of Directional Coupler (db)} + \text{Power Bridge Reading (dbm)}$$

The gain of the tube is given by the equation:

$$\text{Gain (db)} = \text{Pout (dbm)} - \text{Pin from Signal Generator (dbm)}$$

The above gain measurement is valid for both small-signal gain and gain measured in the saturation region and beyond.

STANDING-WAVE RATIO OR REFLECTION COEFFICIENT MEASUREMENT

For direct measurement of voltage standing-wave ratio (VSWR), the coaxial slotted line is the

simplest method. It is essential to have an untuned detector on the slotted line, however, in order to speed up broadband measurements.

When it is necessary to examine the VSWR continuously over a wide frequency range, and where fast checks are required such as on production test setups, the slotted line type of measurement becomes prohibitively time consuming and laborious.

For such situations, the measurement of reflection coefficient through the use of directional couplers is recommended. Two directional couplers which are connected so that one gives an output proportional to the incident wave and the other an output proportional to the reflected wave from the load are used. These two outputs can be detected and compared with a ratiometer to give a direct reading of reflection coefficient. The reflection coefficient is then converted to equivalent VSWR if necessary. The greater the accuracy required in the measurement of reflection coefficient, the higher must be the directivity of the directional couplers. In waveguide, directivity greater than 40 db over the waveguide range can be obtained which allows measurement of reflection coefficient of 0.1 with an accuracy of ±.02. This means that a load VSWR of 1.2 will give an indicated reading between 1.15 and 1.25. A waveguide to coaxial transition can be used to adapt the reflectometer to coaxial systems, but residual reflection in the transition limits the accuracy at low VSWRs.

Once the initial calibration is performed in such a reflectometer system, it is only necessary to tune the signal generator across the frequency range and read the reflection coefficient values directly. An excellent detailed discussion of this method, its errors and limitations, is given in the Hewlett-Packard Journal, Volume 6, Number 1-2, Sept. - Oct., 1954.

Even faster measurements can be made when a swept oscillator is employed. Reflection coefficient can be displayed directly on a scope as a function of frequency, and the measurement can be made at a glance.

INSERTION LOSS MEASUREMENT

Measurement of insertion loss in the range of 40 to 100 db (e.g., cold loss measurement in a traveling-wave tube) over a wide range of frequencies is not uncommon. Such a measurement cannot be made with a 1 milliwatt signal generator and a broadband detector, for this type of system does not have the power levels, nor the sensitivity, to measure much more than 45 db insertion loss.

Wideband measurements can be made quickly and easily, however, with the use of one or two traveling-wave tubes as amplifiers. Use of a traveling-wave tube with a noise figure of 20 db ahead of the detector gives a sensitivity into a broadband detector on the order of −65 to −75 dbm. This alone allows insertion loss measurements of 65 to 75 db. Further, if the output of the signal generator is amplified to the power level of one watt (+ 30 dbm) by using a medium power traveling-wave tube, the total insertion loss then measurable becomes 95 to 105 db.

Since traveling-wave tubes are broadband, untuned devices, the only adjustment necessary in this system as frequency is changed across the band is the tuning of the signal generator. The insertion loss measurement is made in the same manner as the insertion gain measurement shown in Figure 1 except for the addition of the amplifiers before and after the switches. Commercially available switches, when connected as shown in Figure 1, have been measured which have a combined crosstalk ratio in excess of 120 db This, of course, eliminates any crosstalk error in insertion loss measurements in the range of 95 to 105 db.

NOISE FIGURE MEASUREMENT

When one is interested in measuring noise

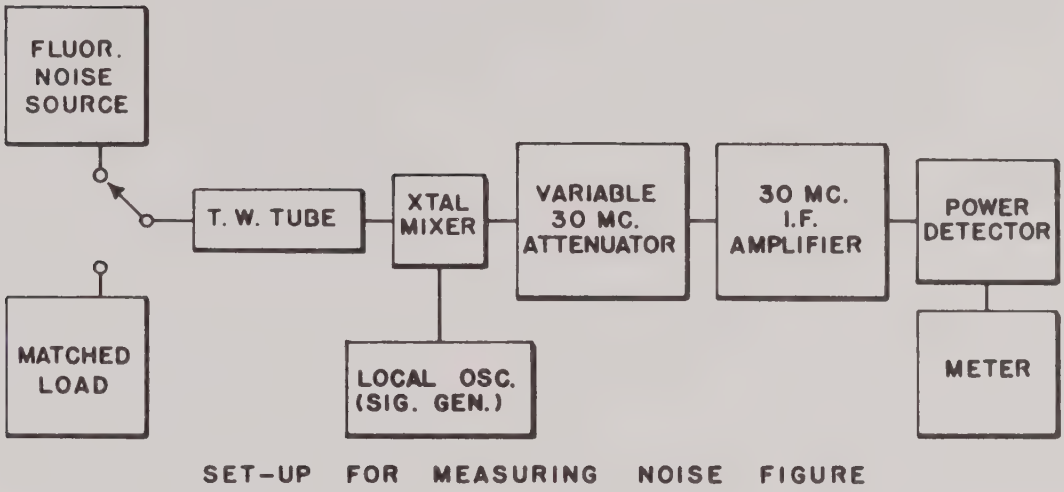

Figure 3. System for Measuring Noise Figure.

figure at a number of frequencies over a wide frequency band, a system which employs a fluorescent tube noise source and a superheterodyne receiver with a square-law second detector (i.e., a power detector) can be used. If noise figure does not vary too rapidly with frequency, a simple receiver can be used which employs an untuned crystal mixer, a local oscillator, a 30 mc IF strip, and a power detector. Note that no preselection or mixer tuning is used.

Without a preselector, the receiver will respond equally well to both the signal and image frequencies. With a 30 mc IF amplifier, these two frequencies will be only 60 mc apart. The measured noise figure will be an average of the true values at two frequencies 60 mc apart providing noise figure is not a rapid function of frequency. This is accurate enough for most purposes. If noise figure varies so rapidly that it will be appreciably different at two frequencies spaced 60 mc apart, then preselection is necessary.

The noise figure of an amplifier is defined as the ratio of the signal-to-noise ratio at the input of the amplifier to the signal-to-noise ratio at the output of the amplifier, That is,

$$F = \frac{(S/N)in}{(S/N)out} \qquad \text{(power ratio)}$$

When the measurement is made according to the method to be outlined, and a noise source whose level is 15.8 db above thermal noise is used, the above equation becomes:

$$F = \frac{37k}{\frac{P_1}{P_2} - 1} \qquad \text{(power ratio)} \qquad (1)$$

where, P_1 and P_2 are as defined in the measurement procedure below, and k, a number smaller than 1.0, is the cable loss in db between the noise source and the tube converted to a power ratio. (e.g., for cable loss = 1db, k = .794)

When a fluorescent noise source is used, it is not necessary to know the effective RF noise bandwidth of the receiver.

Procedure: The tube to be measured is connected into the system shown in Figure 3. The

power detector in the receiver may take the form of a bolometer or a thermistor operating into a self-balancing wattmeter bridge, or it may be a thermocouple whose output is connected to a microammeter.

With the TWT operating and the local oscillator tuned to the desired frequency, switch the tube input to the noise source. Adjust the variable 30 mc attenuator until the output meter indicates approximately full scale. This is reading P_1.

Then switch the tube input to the matched load. The output meter now indicates P_2. Insert the values of P_1 and P_2 in equation 1 and compute the noise figure. To determine the noise figure in db, merely convert this number to db.

Precautions: The accuracy of this measurement is based on the assumption that the receiver is linear. This will be true if the local oscillator signal is large enough to produce linear mixing and if the IF amplifier is operated in the linear portion of its characteristics.

The measurements should be taken quickly enough so that power meter drift will not effect readings.

ALFRED

Tube Warranty and Replacement Procedure

Tube Replacement

All TWT and BWO tubes furnished in ALFRED instruments are available from ALFRED ELECTRONICS or the tube manufacturer for either warranty or out-of-warranty replacements. Current prices are given in the Replacement Tube Price List. In general, they are about 10% higher than the manufacturers' list price to allow for ALFRED retest to assure complete specification compliance.

Tube Warranty

On ALFRED supplied TWT and BWO tubes used in catalog instruments, ALFRED ELECTRONICS extends the full warranty given by the tube manufacturer current at time of replacement and, in addition, offers the following minimum warranty:

> "Tubes are warranted to meet specifications against defects in workmanship, materials, and construction for a period of one year or a rated number of heater hours, whichever expires first. If a defect occurs during the warranty period, a prorated adjustment will be made based on the list price of the tube and the percentage of rated heater operating hours or the one year period."

Rated hours are:

Type	Power	Warranty
TWTA	1 to 20 mw	2000 hours
TWTA	100 mw to 1 w	1000 hours
TWTA	2 to 10 w	500 hours
TWTA	(low N.F. 10 to 15 db)	1500 hours
BWO	3 to 10 mw	~~500~~ 1000 hours

If a tube should fail within the first 50 hours of heater operation and within two months after shipment, the tube will be replaced at no charge.

RETURN AUTHORIZATION

TO OBTAIN WARRANTY CREDIT THE TUBE SERVICE REPORT MUST BE COMPLETED AND RETURNED WITH THE TUBE.

Return Procedure

In case of tube or instrument failure, please contact the factory or your local sales representative for advise or authorization to return either the tube or the instrument to the factory. NO TUBE OR INSTRUMENT WILL BE ACCEPTED FOR REPAIR OR CREDIT ADJUSTMENT WITHOUT WRITTEN AUTHORIZATION AND ACCOMPANYING SERVICE REPORT.

When the authorization is received, pack the tube in a rigid container (use original carton if available) at least 4" larger than the tube in each dimension. Wrap the tube with 1/4" of soft padding material and heavy kraft paper before placing in container. Pack at least 2" of resilient dunnage such as rubberized hair, foam, or similar shock absorbing material completely all around the tube. Mark the container "FRAGILE" and ship PREPAID via air freight, air express or rail express. Do not ship via parcel post or air parcel post since experience has shown that fragile items are more apt to be damaged when shipped via these methods. At least 6" of rubberized hair (or equivalent shock absorbing material) is required for an instrument.

Repairable Tube

If the returned tube is found to be repairable, the user will be asked to issue a purchase order for repair charges determined by the original tube manufacturer. In general, the repair will be at no cost if the tube is in warranty and there is no evidence of misuse or abnormal conditions of operation.

End of Life Replacement

Near the end of tube life, or for other reasons, if tube performance is deteriorating slowly, it may be desirable to continue operating with the defective tube while a replacement tube is being processed. In this case ALFRED ELECTRONICS should be notified as soon as possible of the condition of the tube and a purchase order issued for a replacement tube at list price. Only if the defective tube and service report are received within 3 weeks after date of shipment of the replacement tube, will warranty credit be based on the date defective TWT notification was received at ALFRED ELECTRONICS. The replacement tube is the property of the buyer. However, should the defective tube be repairable, a purchase order should be issued to cover the repair charge.

Warranty Credit

Any applicable credit allowed under the terms of this warranty applies only toward the future purchase of a replacement tube from ALFRED ELECTRONICS. Cash settlements will not be made. In terms of this warranty, a replacement tube must be the same type as that on which credit is allowed. Credit for one tube only may be applied toward the purchase of a single replacement tube. Warranty credit remains in effect for a maximum of 6 months from date ALFRED ELECTRONICS notifies the customer. All credits will be based on the purchase price of the tube which prevails at the time the order for a replacement tube is received by ALFRED ELECTRONICS.

BWO RF Cables

RF OUTPUT CABLE MUST ACCOMPANY BWO TUBES returned for warranty credit, repair, or replacement. If rf output cable is NOT returned, the cable price is added to the normal BWO repair or replacement charge.

Special Conditions

If a returned tube or instrument proves not to be defective after test and evaluation at ALFRED ELECTRONICS, the tube or instrument will be returned at the customer's expense.

The final determination as to whether the tube failed in normal operation thereby bringing it under the applicable warranty or whether the tube was misused thereby excluding it from application of the warranty provisions lies solely with the tube manufacturer.

Data, warranty credit, and prices subject to change without notice.

11/21/62

ALFRED ELECTRONICS

Service Report

Instrument Model _____ Serial No. _____ Date Received _____

TW/BWO Tube Type _____ Serial No. _____ Date Received _____

Date First Tested _____ Date Placed in Service _____ Date of Failure _____

Total Number of Hours of TWT/BWO Heater Operation _____

_____

1. Was operation normal just prior to failure? Yes _____ No _____
2. If not, what was done to adjust it? _____

   _____

   _____
3. Has proper cooling been maintained during tube operation? _____

   _____
4. Did helix overcurrent tripout occur? _____

   _____
5. Was environment normal? (specify) _____

   _____
6. Symptoms - (describe failure) _____

   _____

   _____
7. Operating conditions at time of failure (indicate any unusual conditions) _____

   _____

   _____
8. Name of person to contact regarding evaluation of failure _____

   Telephone No. _____ Signature _____

   Title _____

   Date _____

ALFRED

Tube Warranty and Replacement Procedure

Tube Replacement

All TWT and BWO tubes furnished in ALFRED instruments are available from ALFRED ELECTRONICS or the tube manufacturer for either warranty or out-of-warranty replacements. Current prices are given in the Replacement Tube Price List. In general, they are about 10% higher than the manufacturers' list price to allow for ALFRED retest to assure complete specification compliance.

Tube Warranty

On ALFRED supplied TWT and BWO tubes used in catalog instruments, ALFRED ELECTRONICS extends the full warranty given by the tube manufacturer current at time of replacement and, in addition, offers the following minimum warranty:

> "Tubes are warranted to meet specifications against defects in workmanship, materials, and construction for a period of one year or a rated number of heater hours, whichever expires first. If a defect occurs during the warranty period, a prorated adjustment will be made based on the list price of the tube and the percentage of rated heater operating hours or the one year period."

Rated hours are:

Type	Power	Warranty
TWTA	1 to 20 mw	2000 hours
TWTA	100 mw to 1 w	1000 hours
TWTA	2 to 10 w	500 hours
TWTA	(low N.F. 10 to 15 db)	1500 hours
BWO	3 to 10 mw	~~500~~ 1000 hours

If a tube should fail within the first 50 hours of heater operation and within two months after shipment, the tube will be replaced at no charge.

RETURN AUTHORIZATION

TO OBTAIN WARRANTY CREDIT THE TUBE SERVICE REPORT MUST BE COMPLETED AND RETURNED WITH THE TUBE.

Return Procedure

In case of tube or instrument failure, please contact the factory or your local sales representative for advise or authorization to return either the tube or the instrument to the factory. NO TUBE OR INSTRUMENT WILL BE ACCEPTED FOR REPAIR OR CREDIT ADJUSTMENT WITHOUT WRITTEN AUTHORIZATION AND ACCOMPANYING SERVICE REPORT.

When the authorization is received, pack the tube in a rigid container (use original carton if available) at least 4" larger than the tube in each dimension. Wrap the tube with 1/4" of soft padding material and heavy kraft paper before placing in container. Pack at least 2" of resilient dunnage such as rubberized hair, foam, or similar shock absorbing material completely all around the tube. Mark the container "FRAGILE" and ship PREPAID via air freight, air express or rail express. Do not ship via parcel post or air parcel post since experience has shown that fragile items are more apt to be damaged when shipped via these methods. At least 6" of rubberized hair (or equivalent shock absorbing material) is required for an instrument.

Repairable Tube

If the returned tube is found to be repairable, the user will be asked to issue a purchase order for repair charges determined by the original tube manufacturer. In general, the repair will be at no cost if the tube is in warranty and there is no evidence of misuse or abnormal conditions of operation.

End of Life Replacement

Near the end of tube life, or for other reasons, if tube performance is deteriorating slowly, it may be desirable to continue operating with the defective tube while a replacement tube is being processed. In this case ALFRED ELECTRONICS should be notified as soon as possible of the condition of the tube and a purchase order issued for a replacement tube at list price. Only if the defective tube and service report are received within 3 weeks after date of shipment of the replacement tube, will warranty credit be based on the date defective TWT notification was received at ALFRED ELECTRONICS. The replacement tube is the property of the buyer. However, should the defective tube be repairable, a purchase order should be issued to cover the repair charge.

Warranty Credit

Any applicable credit allowed under the terms of this warranty applies only toward the future purchase of a replacement tube from ALFRED ELECTRONICS. Cash settlements will not be made. In terms of this warranty, a replacement tube must be the same type as that on which credit is allowed. Credit for one tube only may be applied toward the purchase of a single replacement tube. Warranty credit remains in effect for a maximum of 6 months from date ALFRED ELECTRONICS notifies the customer. All credits will be based on the purchase price of the tube which prevails at the time the order for a replacement tube is received by ALFRED ELECTRONICS.

BWO RF Cables

RF OUTPUT CABLE MUST ACCOMPANY BWO TUBES returned for warranty credit, repair, or replacement. If rf output cable is NOT returned, the cable price is added to the normal BWO repair or replacement charge.

Special Conditions

If a returned tube or instrument proves not to be defective after test and evaluation at ALFRED ELECTRONICS, the tube or instrument will be returned at the customer's expense.

The final determination as to whether the tube failed in normal operation thereby bringing it under the applicable warranty or whether the tube was misused thereby excluding it from application of the warranty provisions lies solely with the tube manufacturer.

Data, warranty credit, and prices subject to change without notice.

11/21/62

ALFRED ELECTRONICS

Service Report

Instrument Model _____ Serial No. _____ Date Received _____

TW/BWO Tube Type _____ Serial No. _____ Date Received _____

Date First Tested _____ Date Placed in Service _____ Date of Failure _____

Total Number of Hours of TWT/BWO Heater Operation _____

_____

1. Was operation normal just prior to failure? Yes _____ No _____

2. If not, what was done to adjust it? _____

_____

_____

3. Has proper cooling been maintained during tube operation? _____

_____

4. Did helix overcurrent tripout occur? _____

_____

5. Was environment normal? (specify) _____

_____

6. Symptoms - (describe failure) _____

_____

_____

7. Operating conditions at time of failure (indicate any unusual conditions) _____

_____

_____

8. Name of person to contact regarding evaluation of failure _____

Telephone No. _____ Signature _____

Title _____

Date _____

SHIPMENT DAMAGE CLAIM

The instrument should be tested as soon as it is received. If it fails to operate properly or is damaged in any way, a claim must be filed with the carrier. Have carrier agent inspect damage to instrument and packing crate and forward us a copy of his written report. You will then be advised of replacement or repair arrangements and disposition of the equipment. Please include model number, type number and serial number when referring to this instrument for any reason.

WARRANTY

ALFRED products are warranted against defects in workmanship and materials. This warranty is limited to repair or replacement of products or parts (except tubes, transistors, and batteries) which prove defective within one year after delivery to original purchaser. ALFRED ELECTRONICS is not liable for consequential damage.

If any fault develops:

1. Notify us, giving full details of the difficulty, including the model number, type number and serial number. Upon receipt of this information you will be sent service instructions or shipping data.

2. Upon receipt of shipping instructions forward the instrument prepaid, and repairs will be made at the factory. If requested, an estimate of the charges will be made before the work begins when instrument is not covered by this warranty.

PACKING

The instrument should be packed in the original carton. If unusable or not available, use a wooden box with approximately three inches of excelsior or other shock-absorbing material surrounding the instrument. If desired, packing services of a local Transfer and Storage company may be employed.